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New HiggsBounds from LEP and the Tevatron *

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Abstract

We review the program HiggsBounds that tests theoretical predictions of models with arbitrary Higgs sectors against the exclusion bounds obtained from the Higgs searches at LEP and the Tevatron. We explicitly list the bounds that have been added after the first release of HiggsBounds.

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Abstract. We review the program HiggsBounds that tests theoretical predictions of models with arbitrary Higgs sectors against the exclusion bounds obtained from the Higgs searches at LEP and the Tevatron. We explicitly list the bounds that have been added after the first release of HiggsBounds.

Keywords: Higgs boson, Higgs search, LEP, Tevatron

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INTRODUCTION

The search for Higgs bosons is a major cornerstone of the physics programs of past, present and future high energy colliders. The LEP and Tevatron experiments, in particular, turned the non-observation of Higgs bosons into constraints on the Higgs sector, which can be very useful in reducing the available parameter space of particle physics models. Such constraints will continue to be important far into the LHC era as they will need to be taken into account in the interpretation of any new physics scenario.

The constraints are provided by experiments in the form of limits on cross sections of individual signal topologies (such as $e^+e^- \rightarrow h_i Z \rightarrow b\bar{b}Z$ or $p\bar{p} \rightarrow h_i Z \rightarrow b\bar{b}l^+l^-$) or in the form of combined limits for a specific model, such as the SM. The latter type of analyses include detailed knowledge of the overlap between the individual experimental searches, and therefore have a high sensitivity, whereas the former can be used to test a wide class of models.

Comparing the predictions of a particular model with the existing experimental bounds on the various search topologies can be quite a tedious task as it involves the implementation of experimental results that are distributed over many different publications and combining these results requires a procedure to ensure the correct statistical interpretation of the exclusion bounds obtained on the parameter space of the model.

The program HiggsBounds [1] is a tool designed to facilitate the above task so that wide classes of models can easily be checked against the state-of-the-art results from Higgs searches. This should be useful for applications in Higgs phenomenology and model building (see, e.g., [2, 3]). HiggsBounds takes theoretical Higgs sector predictions, e.g. for a particular parameter scenario of a model beyond the SM, as input. It determines which Higgs search analysis has the highest exclusion power according to a list of expected exclusion limits from LEP and the Tevatron (an expected limit

corresponds to the bound that one would obtain in the hypothetical case of an observed distribution that agrees precisely with the background expectation). In order to ensure the correct statistical interpretation of the obtained exclusion bound as a 95% CL, the comparison of the model with the experimental limits has to be restricted to the single channel that possesses the highest statistical sensitivity. For this channel, the program then compares the theoretical prediction for the Higgs production cross section times decay branching ratio with the actual experimental limit and determines whether or not the considered parameter point of the model is excluded at 95% CL.

THE CODE HIGGSBOUNDS

The code roughly works as follows. The user provides the Higgs sector predictions of the model (point in the parameter space) under consideration. For each neutral Higgs boson h_i ($i = 1, \dots, n_{\text{Higgs}}$) in the model, this will usually include the mass, total decay width, branching ratios and Higgs production cross sections:

$$M_{h_i}, \Gamma_{\text{tot}}(h_i), \text{BR}_{\text{model}}(h_i \rightarrow \dots), \sigma_{\text{model}}(P)/\sigma_{\text{ref}}(P). \quad (1)$$

Where it exists, $\sigma^{\text{SM}}(P)$ is used as the reference cross section. Variations on this input format are offered. As an example, the branching ratios and production cross section can be replaced by the effective couplings of the Higgs boson(s) to SM particles. More details are given in the `HiggsBounds` manual [1].

A complete list of the experimental analyses included in the first release of `HiggsBounds` is given in [1]. The included results from LEP and the Tevatron consist of tables of expected (based on MC simulations with no signal) and observed 95% CL cross section limits, with a variety of normalizations. The set mainly consists of analyses for which model-independent limits were published. However, we also included some dedicated analyses carried out for the case of the SM. These analyses are only taken into account as a possible exclusion bound if the Higgs boson in question would appear sufficiently ‘SM-like’ to this analysis. Roughly speaking, this requires that the ratios of all involved couplings to the SM couplings are approximately equal.

For each Higgs process X (here, we treat each combination of Higgs bosons in each experimental analysis as a separate X), `HiggsBounds` uses the input to calculate the quantity $Q_{\text{model}}(X)$, which, up to a normalization factor, is the predicted cross section times branching ratio for X . In order to ensure the correct statistical interpretation of the results, it is crucial to only consider the experimentally observed limit for one particular X . Therefore, `HiggsBounds` must first determine X_0 , which is defined as the process X with the highest statistical sensitivity for the model point under consideration. In order to do this, the program uses the tables of expected experimental limits to obtain a quantity Q_{expec} corresponding to each X . The process with the largest value of $Q_{\text{model}}/Q_{\text{expec}}$ is chosen as X_0 . `HiggsBounds` then determines a value for Q_{obs} for this process X_0 , using the appropriate table of experimentally observed limits. If

$$Q_{\text{model}}(X_0)/Q_{\text{obs}}(X_0) > 1, \quad (2)$$

`HiggsBounds` concludes that this particular parameter point is excluded at 95 % CL.

The HiggsBounds package (current version 1.2.0) can be obtained from

<http://www.ippp.dur.ac.uk/HiggsBounds>

The code has both a Fortran 77 and Fortran 90 version. It can be operated in a command line mode that can process input files in a variety of formats, as a subroutine suitable for inclusion in user applications, and as an online version, available at its home page. The package includes sample programs which demonstrate how HiggsBounds can be used in conjunction with the widely used MSSM Higgs sector programs FeynHiggs [4, 5, 6, 7] and CPsuperH [8].

NEWLY IMPLEMENTED AND UPDATED BOUNDS

After the first release of HiggsBounds more search channels from LEP [9, 10, 11, 12] and the Tevatron [13, 14, 15, 17, 31] have been implemented on top of what is described in [1]. These newly implemented bounds are summarized in Tab. 1.

TABLE 1. Summary of newly implemented bounds into HiggsBounds after its first release [1]. h_k denotes a generic neutral Higgs boson, while H denotes a SM-like Higgs boson.

$e^+e^- \rightarrow h_k Z \rightarrow X + Z$ [11]	$e^+e^- \rightarrow h_k Z \rightarrow \gamma\gamma Z$ [12]
$p\bar{p} \rightarrow h_k V \rightarrow b\bar{b} + \text{missing } E_T$ [13, 14]	$p\bar{p} \rightarrow H + X \rightarrow WW + X$ [15, 16]
$p\bar{p} \rightarrow h_k b \rightarrow \tau^+\tau^- b$ [17]	$p\bar{p} \rightarrow H + X$ (SM combined) [18, 19, 20, 21]

The code is constantly kept up-to-date by the inclusion of updated results published by the Tevatron experiments. This is illustrated in Tab. 2, where we list the search channels that have been updated since the initial release.

TABLE 2. Summary of Tevatron bounds that have been updated within HiggsBounds after its first release [1]. h_k denotes a generic neutral Higgs boson, while H denotes a SM-like Higgs boson.

$p\bar{p} \rightarrow h_k Z \rightarrow b\bar{b}l\bar{l}$ [22, 23, 24]	$p\bar{p} \rightarrow h_k W \rightarrow b\bar{b}l\nu_l$ [25, 26, 27, 28]
$p\bar{p} \rightarrow h_k W \rightarrow WWW \rightarrow l\nu_l l\nu_l + X$ [29, 30]	$p\bar{p} \rightarrow H + X \rightarrow \gamma\gamma + X$ [31, 32]
$p\bar{p} \rightarrow h_k \rightarrow \tau^+\tau^-$ [33, 34, 35]	

Still missing are the bounds on charged Higgs bosons from both LEP and the Tevatron. They will be implemented into HiggsBounds in the near future.

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REFERENCES

1. P. Bechtle, O. Brein, S. Heinemeyer, G. Weiglein and K. Williams, to appear in *Comput. Phys. Commun.*, arXiv:0811.4169 [hep-ph]. See www.ippp.dur.ac.uk/HiggsBounds.
2. S. Heinemeyer, V.A. Khoze, M.G. Ryskin, M. Tasevsky and G. Weiglein, *Eur. Phys. J. C* **53**, 231 (2008); [arXiv:0909.4665 [hep-ph]].
3. O. Buchmueller *et al.*, arXiv:0907.5568 [hep-ph]; S. Heinemeyer, arXiv:0909.4662 [hep-ph];
4. S. Heinemeyer, W. Hollik and G. Weiglein, *Comput. Phys. Commun.* **124** (2000) 76, [arXiv:hep-ph/9812320]; see: www.feynhiggs.de.
5. S. Heinemeyer, W. Hollik and G. Weiglein, *Eur. Phys. J. C* **9** (1999) 343 [arXiv:hep-ph/9812472].
6. G. Degrandi, S. Heinemeyer, W. Hollik, P. Slavich and G. Weiglein, *Eur. Phys. J. C* **28** (2003) 133.
7. M. Frank, T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak and G. Weiglein, *JHEP* **0702** (2007) 047.
8. J. Lee *et al.*, *Comput. Phys. Commun.* **156** (2004) 283; J. Lee, M. Carena, J. Ellis, A. Pilaftsis and C. Wagner, *Comput. Phys. Commun.* **180**, 312 (2009).
9. [LEP Higgs working group], *Phys. Lett. B* **565** (2003) 61 [arXiv:hep-ex/0306033].
10. [LEP Higgs working group], *Eur. Phys. J. C* **47** (2006) 547 [arXiv:hep-ex/0602042].
11. OPAL collaboration, *Eur. Phys. J. C* **27** (2003) 311 [arXiv:hep-ex/0206022].
12. LEP Higgs Working Group, LHWG Note 2002-02, see lephiggs.web.cern.ch/LEPHIGGS/papers/July2002_Photonic.
13. CDF collaboration, CDF Note 9891; *Phys. Rev. Lett.* **100** (2008) 211801 [arXiv:0802.0432 [hep-ex]].
14. DØ collaboration, *Phys. Rev. Lett.* **101** (2008) 251802 [arXiv:0808.1266 [hep-ex]].
15. CDF collaboration, CDF Note 9887, see www-cdf.fnal.gov/physics/new/hdg/results/hwmmenn_090814/.
16. DØ collaboration, DØ Note 5871-CONF, see www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H68/.
17. DØ collaboration, DØ Note 5985-CONF; *Phys. Rev. Lett.* **102** (2009) 051804.
18. CDF Collaboration and D0 Collaboration, arXiv:0903.4001 [hep-ex].
19. CDF collaboration, CDF Note 9897.
20. V. Abazov *et al.* [DØ Collaboration], *Phys. Lett. B* **663** (2008) 26 [arXiv:0712.0598 [hep-ex]].
21. CDF collaboration, CDF Note 9674, see www-cdf.fnal.gov/physics/new/hdg/results/combcdf_090116/.
22. DØ collaboration, DØ Note 5876-CONF, see www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H71/.
23. T. Aaltonen *et al.* [The CDF Collaboration], arXiv:0908.3534 [hep-ex]; see www-cdf.fnal.gov/physics/new/hdg/results/zhllbb_090724/PAGE/.
24. CDF collaboration, CDF Note 9889, see www-cdf.fnal.gov/physics/new/hdg/results/combcdf_aug09/.
25. DØ collaboration, DØ Note 5972-CONF, see www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H65/.
26. T. Aaltonen *et al.* [CDF Collaboration], *Phys. Rev. Lett.* **103** (2009) 101802.
27. V. Abazov *et al.* [D0 Collaboration], *Phys. Rev. Lett.* **102** (2009) 051803 [arXiv:0808.1970 [hep-ex]].
28. CDF collaboration, see www-cdf.fnal.gov/physics/new/hdg/results/whlnubb_090814/WH4.3fb.html.
29. DØ collaboration, DØ Note 5873-CONF, see www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H74/.
30. CDF collaboration, CDF Note 7307 version 3, see www-cdf.fnal.gov/physics/new/hdg/results/whwww_080411/.
31. DØ collaboration, DØ Note 5858-CONF, see www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H66/.
32. V. Abazov *et al.* [DØ Collaboration], *Phys. Rev. Lett.* **102** (2009) 231801 [arXiv:0901.1887 [hep-ex]].
33. CDF collaboration, CDF Note 9888; DØ collaboration, DØ Note 5980-CONF, see www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H80/.
34. T. Aaltonen *et al.* [CDF Collaboration], arXiv:0906.1014 [hep-ex].
35. DØ collaboration, DØ Note 5740-CONF, see www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H59/.